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Mass-Customization: From Personalized Products to Personalized Engineering Education

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1. Introduction

During the past two decades, organizations have transitioned from the model of mass-production to the model of mass-customization of products as a way to maintain their competitiveness. Mass-customization refers to the ability *“to customize products quickly for individual customers or for niche markets at a cost, efficiency and speed close to those of mass production, relying on limited forecasts and inventory”* [1]. The key objective in mass-customization is to design products that can be rapidly customized to satisfy a variety of different requirements. While the notion of mass-customization has increased the capabilities of organizations to satisfy diverse customer needs, the costs for mass-customization are considerably higher than those for mass production [1]. Hence, the primary design challenge is to keep the costs low while maintaining high customizability. To address this challenge, the key design principles to enable mass-customization are product platforms, modular design [2], ease of replacing components, part standardization, adjustable designs, dimensional customization, dimensional standardization, supply chain customization, and maximization of external variety while minimizing internal variety [3, 4]. Platform design simplifies product offerings and reduces part variety by standardizing components so as to reduce manufacturing and inventory costs and manufacturing variability (i.e., the variety of parts that are produced in a given manufacturing facility), thereby improving quality and customer satisfaction [4].

In this chapter, we discuss our efforts towards adapting the paradigm of mass-customization from product development to the domain of engineering education. Our rationale for doing this is anchored in the continuing process of globalization and its ramifications on the education sector. In a world in which change is the order of the day, it no longer makes sense to offer a one-size-fits-all education as the competencies required in the workforce of near tomorrow vary significantly from one individual to another. In

addition, there is a worldwide increasing demand for online education to accommodate students that, for a number of reasons, are not able to participate in traditional onsite education. In order to address these challenges, the National Academy of Engineering (NAE) has declared 'Advance Personalized Learning' as one of their Grand Challenges, along with, for example, the development of new energy systems. Reflecting on this and relating it to the evolution of product design, the similarities between personalizing products and services in general and educational programs and delivery modes in particular are striking. Hence, we decided to apply the paradigm of mass-customization to engineering education and demonstrate how this could be achieved in the context of a graduate design course.

Educational mass-customization supports personalized learning and thereby the development of diverse knowledge and competencies in a class [5, 6]. Specifically, we present an educational model for personalized mass-customization of engineering education suitable for globally dispersed distance-learning settings [7]. Our approach is anchored in scholarship of education and is based on the following *foundational constructs*: constructive alignment, Bloom's taxonomy, learning organizations and a combination of collaborative, cooperative and collective learning [8]. As a part of constructive alignment, an instructor aligns the planned learning activities and assessment tasks with the learning outcomes. Bloom's taxonomy is a model in which learning is partitioned into six domains of knowledge of varying levels of complexity. The taxonomy is used to scaffold different learning activities. The learning organization construct is adopted to transform a traditional passive learning environment into an active person-centric learning environment. Collaborative learning enhances the knowledge of a group by encouraging diverse individuals to learn from each other [9-11]. The foundational constructs are discussed in Section 3.1.

Based on the foundational constructs various *strategies for achieving mass-customization* are discussed. The strategies include a shift in the role of the instructor and students, providing opportunities to learn, shift from lower level to upper levels of learning in Bloom's taxonomy, creating learning communities, embedding flexibility in the course, leveraging diversity, making students aware of the learning process, and scaffolding learning activities. These strategies are discussed in Section 3.2. Our approach to mass-customization of engineering education has been implemented in a graduate level engineering design course offered at Georgia Tech every spring, namely, *ME6102 Designing Open Engineering Systems*¹. An overview of this course, its context and content, the way it has been structured and orchestrated, as well as the lessons learned are presented in Section 4.

Before discussing the details of our approach for mass-customization in education and our implementation in the graduate level course, we discuss the strategies for mass-customization employed in product development in Section 2.1. In Section 2.2, we illustrate how those strategies have been extended to the field of engineering education.

¹ ME6102 continues to be offered and developed by Schaefer at Georgia Tech. It has morphed into AME5740 *Designing for Open Innovation* at the University of Oklahoma. In Fall 2011, Mistree and Panchal jointly offered this course from two locations.

2. Mass-customization – From products to education

2.1 Strategies for mass-customization in product development

Mass-customization is important for product development organizations due to the diverse demands from customers, the need for personalized products, and rapidly evolving expectations of customers. The evolution in customer expectations is partly driven by new products coming to the market as a result of fierce competition among companies. The challenges that companies face in providing mass customized products are due to increased number of parts, manufacturing processes, levels of inventory, information required, time-to-market, and overall system complexity. All these factors result in higher costs associated with product design, manufacturing, assembly, storage, inventory management, customer relationship management, and maintenance. In addition to the internal challenges (i.e., within the product development organization), increased product variety also has the potential of creating mass confusion for customers. If customers are provided too much variety, it increases their effort in choosing the right product. In summary, the primary challenges in providing mass customized products are in achieving product diversity while maintaining the costs, quality, time-to-market, and complexity close to that of mass production.

To address the challenges associated with mass-customization, various strategies have been developed by product development organizations and academic researchers. One of the most popular strategies is the design of product platforms. A product platform is defined as a “set of subsystems and interfaces that form a common structure from which a stream of derivative products can be effectively developed and produced” [12]. The set of products derived from a product platform is called a product family. A family of products shares common technology and addresses related market applications.

A widely known example of a product family is the set of power tools developed by Black and Decker [12]. The family consists of power drills of various sizes: jigsaws, power hammers, grinders, sanders, circular saws, etc. In the early 1970s, each of these products was developed and manufactured independently to address a specific market segment. Hence, the types of parts used in one product were entirely different from the parts used in another product. Such an approach resulted in a wide variety of parts and materials. In other words, the products had a very high internal variety, which resulted in high complexity of operations and resulting high costs. To address this challenge, the company decided to reduce internal variety by creating a common product platform with common parts (such as motors, gearboxes, etc.) across all the products. The resulting benefit was the reduced design and manufacturing cost, and in turn, the price that the customers had to pay. The price reduction was up to 50% in many of their products [12].

The principle that underlies platform design is the maximization of external variety and minimization of internal variety [13]. According to Simpson and coauthors [13], the designers’ goals for platform design are “to simplify the product offering and reduce part variety by standardizing components so as to reduce manufacturing and inventory costs and reduce manufacturing variability (i.e., the variety of parts that are produced in a given manufacturing facility) and thereby improve quality and customer satisfaction”. The product platform strategy is based on four key enablers:

- commonality of components across different products

- modularity of designs
- standardization of interfaces between components
- compatibility of components

There are many advantages of using common components across different products. First, it reduces the complexity associated with manufacturing processes. Second, the inventory costs are also reduced. Third, the assembly and maintenance costs are reduced. Commonality of components can be achieved by modular design and standardization of interfaces among components. Modularity has been extensively studied in the product design literature. Ulrich and Eppinger [14] define modularity based on the mapping between a product's functional and the physical structures. According to the authors, modular architectures have a one-to-one mapping between the functions and the physical components. In addition, any incidental interactions between physical components are minimized. Standardization of interfaces between components reduces the chances of unintended interactions, and increases the compatibility between functionally similar components. Standardization increases the ease of replacing components to address diverse functional needs.

Market Segmentation Grid

Adapted from (Meyer, 1997)

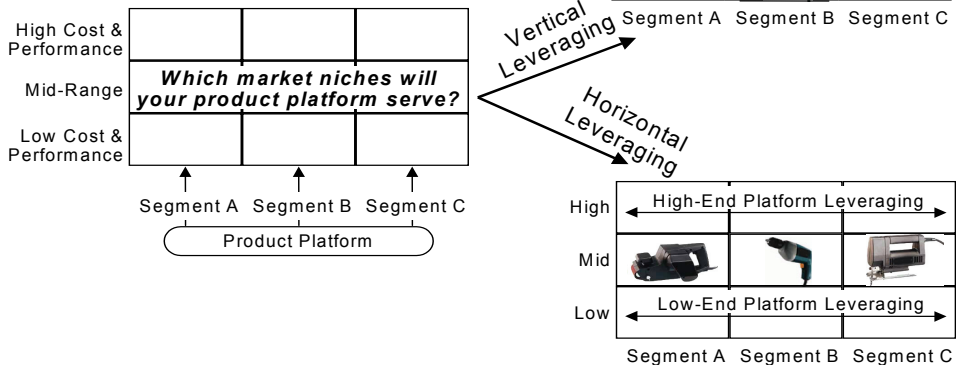


Fig. 1. Illustration of the market segmentation grid and two strategies for platform development (adapted from [15])

The process of designing a product platform starts with the identification of the different market segments. To aid the identification of the market segments, Meyer [15] developed a market segmentation grid with two dimensions – a) the market segments, and b) different tiers of price and performance. The product segments represent customer groups served by the company. The tiers of price and performance are classified into high cost/high performance, mid-range, and low cost/low performance. Having identified the different segments on the market segmentation grid, the next task is to identify the part of the grid

that the company will address first and how it will expand its offerings across the grid. Meyer discussed four strategies: a) niche specific platforms with little sharing of subsystems, b) horizontal leveraging of key subsystems, c) vertical scaling of key platform subsystems, and d) the beachhead strategy. The horizontal and vertical strategies are illustrated in Figure 1. In the horizontal strategy, the product platform is leveraged from one market segment to another in the same tier of price/performance. Similarly, vertical scaling addresses a range of price/performance within a given segment. The beachhead strategy is a combination of the horizontal and vertical strategies. Mass-customization is also related to the concept of customer co-creation where the development of customized products is carried out in close collaboration with the customers [16].

2.2 Extending the concepts of mass-customization to engineering education

In this section, we discuss how the concepts of mass-customization presented in Section 2.1 can be extended to the application domain of engineering education. An overview of the mapping between product development and engineering education that highlights many of the striking similarities between both fields is provided in Table 1. The table is divided into three areas – the need, the organizational goals, and approaches for mass-customization.

2.2.1 The need for mass-customization in engineering education

The first step to developing a strategy for mass-customization is to understand the need. Taking the perspective that students are customers, mass-customization is important because of the diversity of students in terms of their:

- Interests and desired career paths
- Competencies to be gained
- Long-term goals
- Backgrounds
- Learning styles
- Physical locations

Learning in students is directly related to their motivation, which is linked to the value of completing the educational activities. According to Eccles and Wigfield [17], students' expectancy beliefs and subjective task values directly influence performance, effort, persistence, and task choice. The *expectancy for success* is an individual's belief about how well he/she will do on upcoming tasks. If the individual thinks that the activity is too difficult, then he/she will have less motivation to carry out that task. If an individual is confident about completing the task, he/she is more likely to complete it. Since different students have different learning styles, different tasks may be more/less difficult based on how they are structured. Within the framework of expectancy-value theory, value has four components: a) *attainment value*: personal importance of doing well on the task, b) *intrinsic value*: enjoyment that an individual gets from performing the activity, c) *utility value*: how well a task relates to current and future career goals, and d) *cost*: the negative aspects of engaging in a task. Similar to the expectancy for success, good design projects have high attainment, intrinsic, and utility values to the students and low cost.

Product Development	Engineering Education
<i>Need</i>	
Diversity in customer demands	Diversity in the needs of students with different interests, long-term goals, backgrounds, learning styles, locations, and career paths
<i>Organizational Goals</i>	
Maximize external variety and minimize internal variety	Maximize external variety in educational offerings by combining modular resources in various ways
Maximize quality	Improved learning experience for students
Reduced time to market	Reduces time for developing and courseware and delivering courses
Reduced effect on complexity	Reduced complexity of managing courseware
<i>Strategies for Mass-customization</i>	
Product platforms (Maximizing external variety and minimizing internal variety)	A common platform – “Learning to Learn” consisting of Assignment 0, learning organization, Bloom’s taxonomy, etc. (see Table 2).
Customer co-design	Working with the students to define their specific learning objectives and competencies
Product family	Core lectures and elective lectures
Horizontal leveraging and vertical scaling	Scaling: From short courses to semester long courses Horizontal: Across different departments
Compatibility and commonality	Common theme of Question for the Semester (Q4S)
Standardization	Standard structure of the assignments (same set of general questions)
Modularity (Ease of replacing components)	Making self-contained modules of content (including lectures, reading material, etc.)
Adjustable designs	Adjusting the material based on the responses on Assignment 0

Table 1. A mapping between the concepts of mass-customization between product development and engineering education

Accordingly, educational experiences should be structured in a way that maintains 1) high expectancy for the success of diverse students, and 2) provides high attainment, intrinsic and utility values to the students at low costs. This involves finding out students’ prior knowledge and skills before starting the design activity. If an instructor starts with incorrect assumptions about students’ skills, he/she may create educational experiences that are either overly difficult for the students or so trivial that the students lose interest. In such a case, the students’ expectancy for success may be low, and hence, the motivation will also be low. This is analogous to addressing specific customer needs at minimum costs.

2.2.2 Organizational goals for mass-customization

The fundamental goal for any educational institution is to provide the best possible learning experience for the students. Considering the diversity of students, providing customized learning experiences to students can help educational institutions attain their fundamental goal. Additionally, educational institutions are interested in increasing the variety of

educational offerings by catering to: a) students who cannot attend classes physically (due to their location) via online/web-based courses, and b) professionals working full-time via short certificate programs. Such programs not only increase the revenue for the organizations but also enrich the learning experiences of the in-class students (if offered in a blended mode).

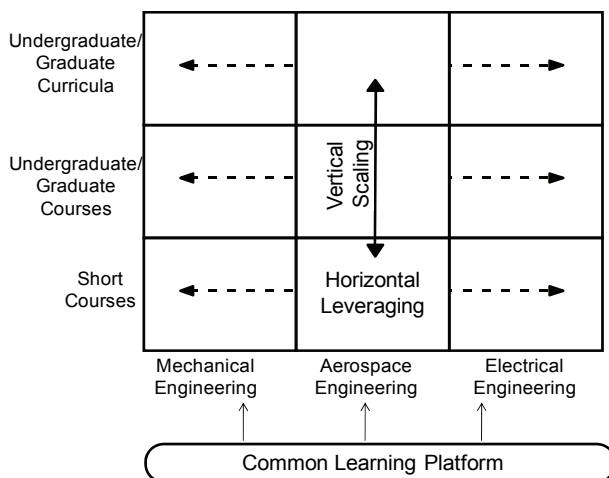


Fig. 2. Using the common learning platform to develop customized courses

At a fundamental level, educational institutions are also based on the mass-production model. For example, a university offers a limited number of degree programs catering to thousands of students; a department offers a limited number of courses for hundreds of students. Very little (if any) flexibility is offered to students by mechanisms such as elective courses and class projects. However, addressing the learning needs of diverse groups of students is challenging. For universities, offering customized degrees to students is challenging both from the management and accreditation standpoints. For instructors, customizing course materials for different students is challenging and requires significant effort and commitment. Further, there is little knowledge available on how to develop “product platforms” for educational material or how to develop standardized learning modules that are suitable for different learning needs (see Figure 2). There is little knowledge on holistic approaches to horizontally leveraging course material across different disciplines (e.g., mechanical engineering, electrical engineering, etc.). Similarly, there is a lack of knowledge about systematic strategies for vertically leveraging educational material for short, undergraduate, and graduate courses. We acknowledge that some instructors have been successful in developing specific courses that span more than one segment in Figure 2. However, those specific initiatives can be compared to hand-crafted personalized products, and do not represent mass-customized products. The effort associated with mass-customization of courses can be discouraging for faculty members at research-oriented universities with significant pressure to perform quality research and recent budget reductions forcing faculty members to teach more courses and with many more students in a class. We believe that these challenges are limiting the adoption of the mass-customization in the field of education.

We believe that some of these challenges can be addressed by adapting the strategies from mass-customization of products to engineering education. Some of the strategies and the underlying educational foundations are discussed in Section 3.

3. Educational foundations and strategies for applying mass-customization in engineering education

3.1 Educational foundations

From an educational standpoint, our approach is based on the following constructs: constructive alignment, Bloom's taxonomy, cooperative, collective and collaborative learning, and a learning organization. Each is discussed in turn in Sections 3.1.1 through 3.1.4.

3.1.1 Constructive alignment

Constructive alignment, a phrase coined by Biggs [18], is one of the influential constructs in higher education. It underpins current requirements for program specification, declarations of intended learning outcomes and assessment criteria, and the use of criterion-based assessment. Constructive alignment consists of two parts:

- students construct meaning from what they do to learn, and
- the professor aligns the planned learning activities with the associated learning outcomes.

The basic premise of the whole system is that the curriculum is designed so that learning activities and associated assessment tasks are aligned with the learning outcomes that are intended in the course. This means that the system is consistent. Constructive alignment fosters clarity in the design of the curriculum, and transparency in the links between learning and assessment. As students learn, the outcomes of their learning display similar stages of increasing structural complexity.

In traditional courses, constructive alignment is achieved by making the students aware of the learning goals and mapping the activities in the course to corresponding learning objectives. In a mass customized educational environment, our approach is to let the students define their own learning objectives and competencies that they want to gain in the course. The activities in the course (such as assignments, learning modules, and project) are aligned to customized learning objectives (defined in Assignment 0, discussed in Section 4.2.2) through a common underlying structure that can be adapted by the students for different learning objectives. The details are provided in Section 4.2.

3.1.2 Bloom's taxonomy

In 1956, Bloom [19] developed a classification of levels of intellectual behavior important in learning. Bloom found that at the time over 95% of the test questions students encountered required them to think only at the lowest possible level, i.e., the recall of information. Bloom identified six levels within the cognitive domain, from the simple recall or recognition of facts, as the lowest level, through increasingly more complex and abstract mental levels, to the highest order which is classified as evaluation. These six levels are: (1) knowledge, (2)

comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation (see Figure 3). Bloom's taxonomy provides a systematic way of describing how a learner's performance grows in complexity when mastering academic tasks. It can thus be used to define curriculum objectives, which describe where a student should be operating. In addition, Bloom's taxonomy provides a powerful means to assess students' performance, justify associated grades, and at the same time provide students with feedback on how to improve their performance. In a truly constructively aligned curriculum it facilitates deep learning as the activities are designed for that purpose.

In our approach, learning activities are scaffolded so that students attain the top levels of the taxonomy in addition to gaining technical knowledge and comprehension. The students are introduced to Bloom's taxonomy at the beginning of the semester. The students define their learning goals in terms of the Bloom's taxonomy (discussed further in Section 4.2.2).

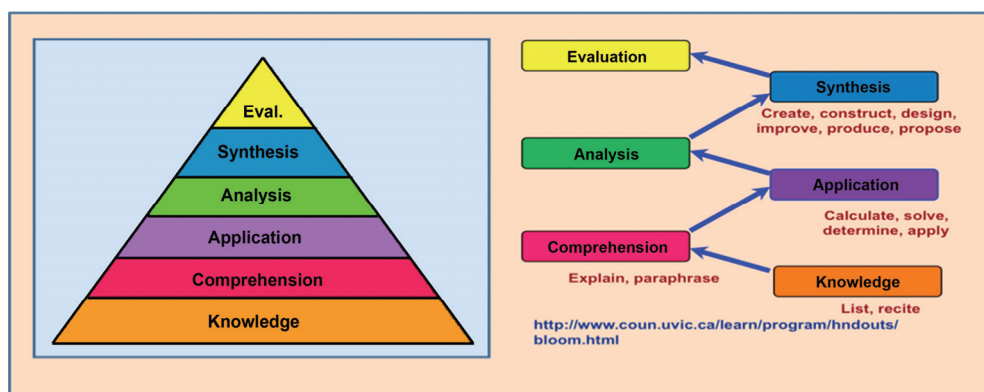


Fig. 3. Bloom's taxonomy of learning

The pedagogical approach adopted in ME6102 embraces elements of collaborative, cooperative, and collective learning. It has been presented in detail in [8]. Research suggests that these instructional approaches foster a deeper understanding of the course content, increased overall achievement of desired learning outcomes, improved self-esteem and higher motivation among students. A brief overview of these instructional approaches with a focus on those aspects most relevant to our pedagogical approach is presented below.

3.1.3 Collaborative and collective learning

Collaborative learning refers to student-centered educational approaches involving joint intellectual effort by learners and instructors. It includes educational methodologies and learning environments in which learners engage in common tasks in which each individual depends on and is accountable to each other. The theory of collaborative learning is tied together by a number of important assumptions about learners and learning processes. These include (a) that learning is an active, constructive process in which learners create new knowledge by using, integrating and reorganizing their prior knowledge; (b) that

learning depends on rich context, which influences the success of learning significantly; (c) that learners are diverse in terms of background, knowledge, experience and learning styles; and (d) that learning is inherently social, which makes student interaction an important part of education. All of these aspects of learning are supported by the means of collaborative learning where students solve problems and create knowledge in a diverse group setting.

The term collaborative learning also involves the use of a collection of tools, which learners can use to collaborate, assist, or be assisted by others like they are used in e-Learning and distance learning environments. Such tools include virtual classrooms, chat rooms, discussion threads, as well as application and document sharing. There are three major forms of collective learning: (a) learning in networks, (b) learning in teams and (c) learning in communities. According to Panitz [20], collaboration is a philosophy of interaction and personal lifestyle and cooperation is a structure of interaction designed to facilitate the accomplishment of an end product or goal. Cooperative learning [20-22] is more directed than student-centered collaborative learning and closely controlled by the course orchestrator. The approach presented in this paper features elements of both philosophies.

In our approach, both individual and collaborative learning are blended together to leverage the diversity of individuals and to extract the benefits of learning within a group environment. The activities that are carried out individually include defining individual learning goals and meta-competencies, defining the future environment, and deep reading exercises. Collective activities include answering the questions posed at the beginning of the semester. The details of individual and collective parts are provided in Section 4.2.3 and illustrated in Figure 4. As alluded to before, the field of collective/collaborative/co-operative learning has developed into a major educational discipline by itself. For a detailed discussion please refer to [20, 21].

3.1.4 The Learning Organization

Another foundational construct of our approach is the formation of a learning community in a distributed distance learning setting. The blueprint for this is the model of the Learning Organization (LO) as introduced by Peter Senge in his book 'The 5th Discipline' [23]. According to Senge, a Learning Organization is "an organization that facilitates the learning of all its members and consciously transforms itself and its context". A learning organization exhibits five main characteristics: (1) systems thinking, (2) personal mastery, (3) mental models, (4) a shared vision, and (5) team learning. A brief overview of these, taken from [24], is presented next.

Systems thinking: The idea of the learning organization developed from a body of work called systems thinking. This is a conceptual framework that allows people to study businesses as bounded objects. Learning organizations use this method of thinking when assessing their company and have information systems that measure the performance of the organization as a whole and of its various components. Systems thinking requires that all the characteristics must be apparent at once in an organization for it to be a learning organization. If some of these characteristics are missing, then the organization will fall short of its goal.

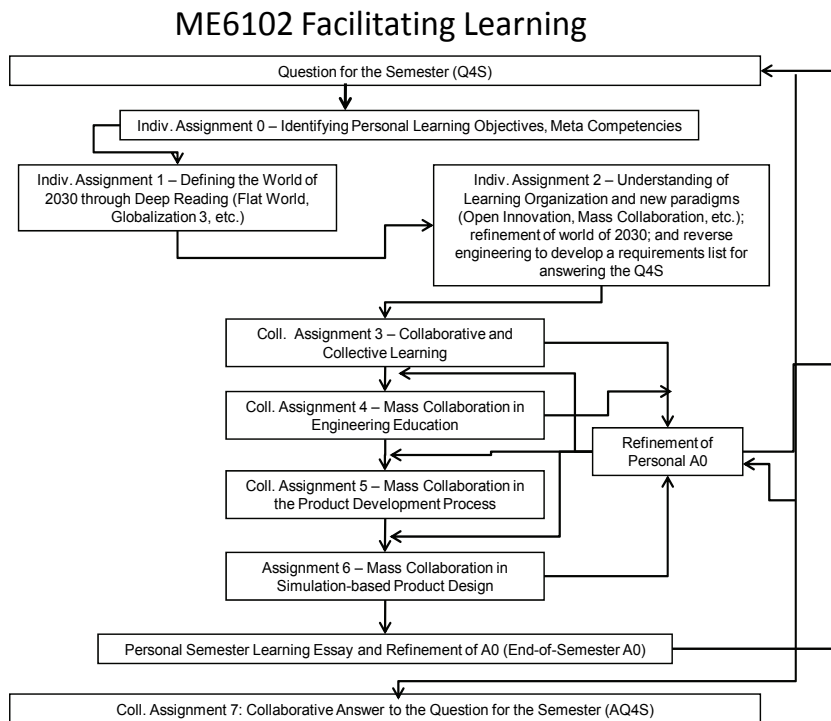


Fig. 4. Relationship between different components of the course

Personal mastery: The commitment by an individual to the process of learning is known as personal mastery. There is a competitive advantage for an organization whose workforce can learn quicker than the workforce of other organizations. Individual learning is acquired through staff training and development, however learning cannot be forced upon an individual who is not receptive to learning. Research shows that most learning in the workplace is incidental, rather than the product of formal training, therefore it is important to develop a culture where personal mastery is practiced in daily life. A learning organization has been described as the sum of individual learning, but there must be mechanisms for individual learning to be transferred into organizational learning.

Mental models: The assumptions held by individuals and organizations are called mental models. To become a learning organization, these models must be challenged. Individuals tend to espouse theories, which are what they intend to follow, and theories-in-use, which are what they actually do. Similarly, organizations tend to have ‘memories’ which preserve certain behaviors, norms and values. In creating a learning environment it is important to replace confrontational attitudes with an open culture that promotes inquiry and trust. To achieve this, the learning organization needs mechanisms for locating and assessing organizational theories of action. Unwanted values need to be discarded in a process called ‘unlearning’.

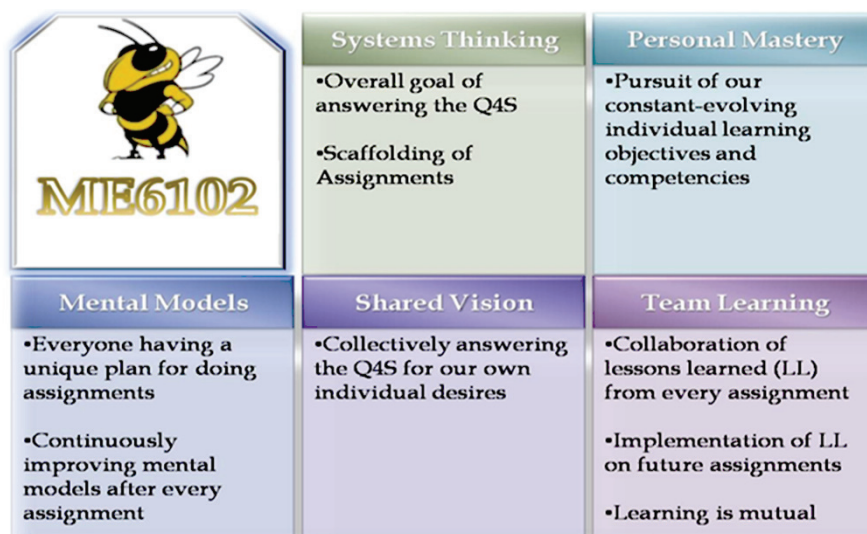


Fig. 5. ME6102 as a learning organization

Shared vision: The development of a shared vision is important in motivating people to learn, as it creates a common identity that provides focus and energy for learning. The most successful visions build on the individual visions of the employees at all levels of the organization, thus the creation of a shared vision can be hindered by traditional structures where the company vision is imposed. Therefore, learning organizations tend to have flat, decentralized organizational structures. The shared vision is often to succeed against a competitor, however Senge states that these are transitory goals and suggests that there should also be long-term goals that are intrinsic within the company.

Team learning: The accumulation of individual learning constitutes team learning. The benefit of team or shared learning is that people grow more quickly and the problem solving capacity of the organization is improved through better access to knowledge and expertise. Learning organizations have structures that facilitate team learning with features such as boundary crossing and openness. Team learning requires individuals to engage in dialogue and discussion; therefore team members must develop open communication, shared meaning, and shared understanding. Learning organizations typically have excellent knowledge management structures, allowing creation, acquisition, dissemination, and implementation of this knowledge in the organization.

The paradigm of the learning organization (LO) was initially developed for companies, based on the business models and practices of the 1990s. To extend the concept of learning organization to educational settings, we analyze the original model of the LO and augment it to better fit the learning needs of the students and the characteristics of the G3 world of near tomorrow. Figure 5 is an illustration of the use of the learning organization framework in the sample course, ME 6102. Systems-thinking is achieved by posing a high-level question for the students to be addressed by scaffolded activities and assignments throughout the semester. The question is referred to as the Question for the Semester (Q4S). The Q4S is

discussed in detail in Section 4.2.1. Personal mastery is achieved by defining and striving to achieve personal learning goals that are tied to the development of competencies and meta-competencies. The students are continuously challenged to understand and assess their mental models. Team learning and shared vision are achieved through the process of collectively completing the assignments and answering the Q4S. The details of the approach are provided in Section 4.

3.2 Strategies for mass-customization in engineering education

One of the barriers to mass-customization within engineering education is that focus is primarily on delivering technical content. The first step towards achieving mass-customization is to shift the focus from technical concepts to the process of learning. This is the fundamental difference between traditional approaches to engineering education and our approach to mass customized education. Analogous to the concept of product platforms, our **learning platform** is centered on the notion of “learning-to-learn”. Hence, the focus is shifted from just delivering technical information to helping students learn how to learn. The learning platform consists of a set of tools (shown in Table 2) whose role in the learning platform is well defined and standardized. The technical content is adapted to suit the specific needs of different courses and disciplines. The courses derived from this common learning platform constitute a *product family*.

Our learning platform for mass-customization in engineering education is centered on the following principles (see Table 2):

- a. *Shift in the role of the instructor:* In traditional engineering courses, the role of instructors is to deliver course content to the students. In contrast, the instructor serves as an orchestrator of learning. The role of orchestrator is to create opportunities for students to learn (both individually and collectively).
- b. *Shift in the role of students:* The role of the students also shifts from being passive learners to active learners. The students play a significant role in the learning process. They define their own learning goals (in consultation with the orchestrators) and are responsible for directing their efforts to achieve their goals.
- c. *Providing the opportunities to learn:* Instead of solely lecture-based learning, the students are provided various opportunities to learn individually and collectively. These opportunities include lectures from instructors and guest speakers, speculation sessions, discussions sessions, self-study time, forming a learning community, virtual collaboration on global scale, creating new knowledge, collaborative group project, reflective practice, and self and peer evaluation.
- d. *Shift in focus from the lower levels to upper levels of learning:* Traditionally, the focus has been on the knowledge of core concepts and their application to technical systems, namely, competencies. The focus in our approach is on higher level learning (i.e., develop meta-competencies) such as the gaining the abilities to analyze, synthesize, and to evaluate (see details in Section 4.2).
- e. *Creation of learning communities:* An underlying principle to achieve successful mass-customization in engineering education is “sharing to gain”, which is achieved by fostering learning communities.

Traditional Concepts in Engineering Education	Principles for Mass-customization	Tools used in ME 6102
Instructors deliver course content	Shift from instructor to an orchestrator who creates opportunities to learn	Assignment 0, Question for the Semester, Learning essays, Project
Students are passive learners	Students are active learners, i.e., take charge of their own learning	Assignment 0, Question for the Semester, Learning essays, Project
Learning goals are fixed by the instructor	Learning goals are defined by the students in collaboration with the orchestrator	Assignment 0
Focus on lower levels of learning	Focus on higher levels of learning	Bloom's taxonomy
Individual learning	Learning communities	Learning organizations (Senge)
Rigid course structure	Embed flexibility in the course	Assignment 0, core and optional modules, ability to adapt the learning tools
Ignore diversity	Leverage diversity	Best practices, collective learning
Learning process unclear to the students	Making students aware of the learning process	Observe-reflect-articulate construct
Independent activities	Scaffolding	Question for the Semester

Table 2. The principles for mass-customization and the tools used in ME 6102

- f. *Embed flexibility in the course*: In contrast to traditional rigid course structures, we embed flexibility in the course by having guest lectures on diverse topics, ask the students to define their own goals, and let the students adapt various parts of the course to suit their learning needs.
- g. *Leveraging diversity*: One of the approaches for leveraging diversity is to share students' unique work with the rest of the class. This is achieved by identifying, distributing and discussing "best practice" submissions.
- h. *Making students aware of the learning process*: In traditional courses, since the focus is on the content, the students are unaware of their learning process. However, in our approach, we make the students aware of the learning process so that they can understand the role of each activity that they are invited to undertake and the relationship of this activity to their learning. This is carried out through the observe-reflect-articulate construct. Each assignment and learning essay is divided into these three parts to bring alive the observe-reflect-articulate construct.
- i. *Scaffolding*: Finally, the most important aspect of our mass-customization approach is scaffolding of the course towards the achievement of individual and collective goals. This is achieved through a question for the semester (Q4S) that is provided to all the students at the start of the semester. All activities in the course are geared towards answering this question.

We have designed a learning platform that embodies the preceding principles and allows us to develop customized courses for different disciplines, technical areas, and at different scales. We have done this for undergraduate and graduate courses in mechanical engineering. This is analogous to horizontal leveraging on the market segmentation grid (see Figure 2). The approach can be scaled down from a course level to a short-course level, and scaled up to a combination of courses (curriculum level). Although the approach has not yet been used for curriculum-level mass-customization, we assert that the underlying principles are valid. We note that the principles are independent of the courses, curricula, or the discipline. Hence, different discipline specific content can be added to develop different courseware. As a result, it serves as a learning platform (product platform) for engineering education that can be customized to generate different courses (products) in the course family (product family). In the following section, we offer the implementation details of the course.

4. Implementation of the approach in a graduate-level engineering design course (ME 6102)

4.1 Overview of ME6102: Designing Open Engineering Systems

ME6102 – “Designing Open Engineering Systems” – is a graduate engineering design course offered at the George W. Woodruff School of Mechanical Engineering at Georgia Institute of Technology. ME6102 is offered to students enrolled at the George W. Woodruff School of Mechanical Engineering’s different Georgia Tech campuses - Atlanta, Savannah, and Lorraine (France) and also by distance learning students who were located all over the world. Most students take ME6102 after they have taken some introductory engineering design course in which they have become familiar with a systematic design approach (such as the one by Pahl and Beitz [25]). The course is offered in both live and distance learning modes. To reach all students, synchronous and asynchronous education techniques are incorporated. The lectures are recorded and uploaded so that all students can access them online at any time. Besides in-class interactions, the students are encouraged to communicate with the course orchestrators via email, telephone, video conference or the online forum on the course website. The online forum also enables communication analogous to social networking websites such as Facebook and LinkedIn. To bring the groups of on-campus and distance-learning students closer to each other, we have developed a collaborative learning framework that enables students to interact through a course internal social network. The framework is based on Web 2.0 technologies such as collaborative wikis, and open source software development principles. Through this web-based framework we provide a variety of tools to support both synchronous and asynchronous communication between the participants. The use of such a framework for collaborative learning also provides students the opportunity to experience the challenges and benefits of mass-collaborative environments [26].

Our goal is to provide an opportunity for students to learn how to create knowledge rather than merely learning how to solve problems encountered in design. The emphasis is on problem identification and formulation in a rapidly changing world that is defined by Globalization 3.0. The course setting provides the opportunity for students to learn how to:

- identify opportunities for creating new systems and improving existing systems in the age of global mass-collaboration.

- identify the competencies required to succeed in a changing marketplace and learning how to gain those competencies.
- design open engineering systems in the presence of uncertainty from a decision-based perspective, i.e., to design systems with characteristics consistent with their natural life-cycle dynamics.
- manage uncertainty and complexity in systems and associated design processes.
- make tradeoffs needed to coordinate multiple objectives associated with the design of open engineering systems.
- develop the ability to critically evaluate literature and use this analysis to identify research issues worth investigating.
- continue learning about designing.

The content of the course is based on three concepts: Open Engineering Systems [27], Globalization 3.0 [28], and Mass Collaboration [29]. The students are challenged to determine the requirements for design approaches to work well in the context of the Globalization 3.0 world with its new, game-changing paradigms of mass collaboration, open-innovation, crowd-sourcing, and the like. Hence, the syllabus also contains topics from economics (e.g., globalization, global markets), business (e.g., value chain, supply chain, outsourcing), law (intellectual property protection), IT (e.g., web 2.0) and social sciences (e.g., social networks, cultural differences, motivation).

4.2 Mass-customization in ME6102

The underlying architecture of the course is designed to provide personalized learning experiences in a group setting. The key components of this architecture include:

- *Question for the Semester* as a common thread to tie the components of the course together
- *Assignment 0* to understand the diverse learning goals and meta-competencies of the students
- *Learning activities* to achieve personal goals in a group setting
- *Assignments* to scaffold the learning experience
- *Project* to customize the core topics in the course to particular application based on students' interests
- *Learning essays and individual feedback* to provide personalized guidance to individual students
- *Best practices* to enable collective learning, and
- *Assignment A0-EOS* for reflection and self-assessment

The relationships between these components are discussed next.

4.2.1 The Question for the Semester

The question for the semester is used to align the efforts of all the students while providing enough flexibility to the students to explore the topics that are particularly interesting to them. The question for the semester is presented to the students during the first lecture. Every student has to answer this question individually by the end of the semester. Examples of the questions for the semester used during Spring 2008 and Spring 2009 are shown below. To support mass-customization of the course, the students are allowed to particularize this

question according to their personal semester goals. The particularization is carried out in consultation with the orchestrators.

Question for the Semester – Spring 2008

Imagine that you are operating a product creation enterprise in the era of Globalization 3.0. Your task is to define your company and develop a business plan. This includes answering the following key questions:

- a. How do you envision the world of 2030 in such an environment?
- b. How do you see yourself and your company operating in this world of 2030? Please take into account your engineering expertise and your passions.
- c. What are the *competencies* that you would require to be successful in such an environment? Please identify the drivers and metrics for success.
- d. What would your strategy for product development be in the world of 2030? What kind of products / processes do you plan to offer? How would you structure your design and manufacturing process? What kind of collaborations with other companies do you envision? What kind of supply chains do you envision your company to be involved in? How would you utilize the intellectual capital available throughout the world?
- e. What would the IT framework for collaborative product realization in 2030 look like?
- f. What kind of a product realization method is necessary for your world of 2030? Please provide phases and steps.

Question for the Semester – Spring 2009

Imagine that you are operating a product creation enterprise in the era of Globalization 3.0 where individuals are empowered to participate in the global value network. Your brief is to identify the characteristics of the IT infrastructure to support the technical collaboration that furthers open innovation.

Question for the Semester – Spring 2011

Imagine that you are operating a product creation enterprise in the era of Globalization 3.0 where individuals are empowered to participate in the global value network. Your brief is to identify and discuss the characteristics, opportunities and challenges of a Product Development Process (Design and Manufacture) that furthers open innovation and is based on crowdsourcing and mass collaboration.

4.2.2 Assignment 0

As a ramification of the ongoing globalization, the skills that were considered valuable yesterday are becoming the commodities of today and tomorrow [30]. Realizing how much the world has changed over the past 10 years, it becomes apparent that this change needs to be better reflected in the way engineers are educated [31-34]. Some educators have articulated that engineering education needs to be considered from a holistic point of view [35-37]. There should be a better symbiosis of societal needs, emerging technologies, cross-disciplinary domain integration, and aspects related to cultural diversity and ethical issues. Our task at hand is to prepare engineers who are capable of identifying and solving

problems that do not yet exist with tools and methods that have not yet been invented. In essence, this boils down to educating students with respect to **learning how to learn** and to **empower them to take charge of their own education**. From the perspective of an individual, this translates to identifying and obtaining the competencies needed to become a valuable asset for a dynamic career. Hence, the first step to customize the course is to let the students identify their personal goals for the semester. In ME6102, this is achieved in an assignment (Assignment 0) which is given during the first class. In this assignment, the students' task is to identify the goals that they want to achieve. These goals are referred to as the *personal semester goals*. The goals consist of learning objectives and meta-competencies that they want to achieve during the semester. The learning objectives and meta-competencies identified by one of the students are shown in Figure 6 as an example.

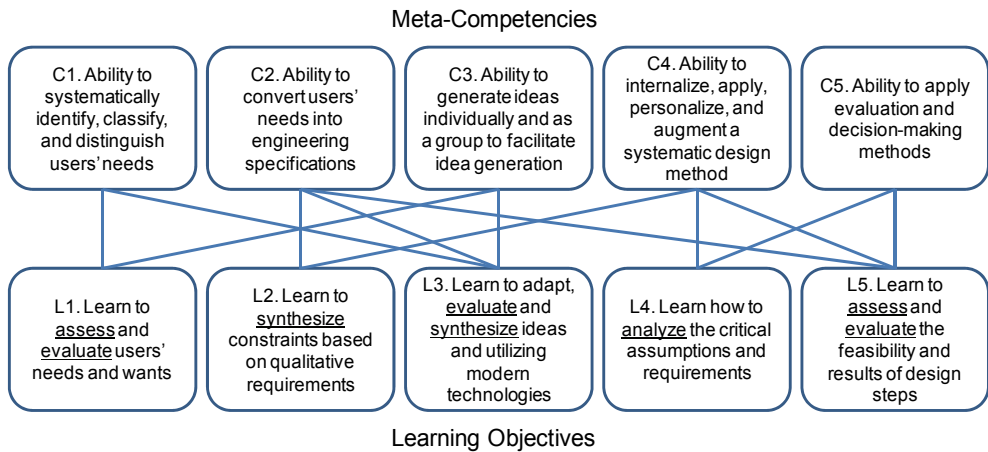


Fig. 6. Examples of Meta-Competencies and Learning Objectives and relationships among them

Competencies are the result of integrative learning experiences in which skills, abilities, and knowledge interact to form bundles that have currency in relation to the task for which they are assembled [38]. On the other hand, learning objectives are generic skills that students wish to attain so that they become competent in performing the task. Learning objectives are defined in terms of the six levels of learning defined in the Bloom's taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation). In the examples of learning objectives, the keywords from Bloom's taxonomy are highlighted.

Having identified the students' personal goals, the course orchestrators use a scaffolding scheme to design a personalized learning experience in a group setting, thereby mass customizing the course to different student needs. In Figure 4, the relations between the different components of the course are depicted. The scaffolding is achieved through the "Question for the Semester" (Q4S) and the various assignments. The assignments are scaffolded and provide opportunity for personalization. This ensures that everybody in the class works in the direction intended by the course orchestrators. The lectures are used to convey core course content and additional aspects that may help students with their assignments and learning essays. While answering the "Collaborative Question for the

Semester” the students work in a mass collaborative manner which provides the opportunity to create new knowledge by combining the diverse knowledge in the personalized section of the course.

Mass-customization in education requires catering to students’ individual needs, skills and interests. This not only leads to a higher motivation of the students but also enables deeper learning. In ME6102, the orchestrators apply a similar approach to mass-customization as presented by Williams and Mistree [6]. The key for providing personalized learning experience in a group setting is an intensive two-way communication between students and the orchestrators. Therefore the course orchestrators have to get to know their students and their personal semester goals. In ME6102, students’ objectives are captured through Assignment 0, which is due at the end of the first week of the semester. The students are asked to provide a brief self-introduction, their expectations of taking this course and their personal semester goals (learning objectives and competencies). They are asked to list five *learning objectives* they want to achieve and five *competencies* they want to gain during the course of the semester. Learning objectives are clear formulations of what a student wants to learn and are usually related to acquisition and creation of knowledge. The details of Assignment 0 are provided in Figure 7.

4.2.3 Individual and collaborative assignments

In ME6102, there are two types of assignments – individual assignments and collaborative assignments. As shown in Figure 4, Assignments 1 and 2 are individual assignments whereas the rest of the assignments are group assignments. In Assignment 1, the students took a closer look at defining their world of 2030 and their views on what a manufacturing enterprise will look like 20 years from today. In Assignment 2, the students identify the components of their answer to the Q4S. In essence, answering the Q4S was their design problem and the answer to this question considered an Open Engineering System they were required to build. Both these assignments are carried out individually in order to maximize the diversity in ideas and to reflect the students’ individual interests and passion within the framework of answer to the Q4S. After this stage, collective assignments help in understanding the concepts of mass collaboration. The exact format of the rest of the semesters is customized every semester.

During 2009, Assignment 3 was focused on creating a Virtual Learning Environment (VLE) for collaborative and collective learning in which to work on the assignments. In addition to the technical aspects, this included forming a learning community in a distributed setting plus establishing policies regarding their collaboration and behavior. This is a step towards forming a distributed learning organization. Assignment 4 was on the concepts of Mass Collaboration in Engineering Education. The students were tasked to identify and analyze Web 2.0 technologies with regard to their appropriateness for professional mass collaborative work. In Assignment 5, the students were to look into the topic of Mass Collaboration in the Product Development Process. This included an analysis with regard to the following phases: 1) Idea Generation, 2) Idea Screening, 3) Concept Development and Testing, 4) Business Analysis, 5) Beta Testing and Market Testing, 6) Technical Implementation, and 7) Commercialization. In addition, methods of Mass Collaboration between the various functional units of corporate enterprises were investigated and requirements for a successful implementation identified. Assignment 6 was on the

application of Mass Collaboration in virtual product realization environments through the utilization of Simulation-based Design.

Assignment 0

Identify Competencies

1. What is your view of a manufacturing enterprise in 2030? Leverage Lecture 01, Friedman, P&G.
2. Critically evaluate your response in Point 1 and then propose the competencies (in bullet form) that you believe are needed to be a successful designer in the world of 2030. Justify. Hint: See Slides 13 and 14, Lecture 2.
3. Critically evaluate the list in Point 2. This will require you to do a self-inventory of your competencies or lack thereof. List (in bullet form) the 5 competencies you propose to develop in ME6102.
 - a. **Compare** what you have written under Points 2 and 3.
 - b. **Assess** the improvement in what you have written in Point 3.
 - c. **Recommend** what additional fixes are necessary,
4. Analyze the competencies listed in Point 3. Classify. Prioritize. Modify/refine. Propose an improved list of competencies you propose to develop. In context of Points 2 and 1 justify your proposed set of competencies.

Identify Learning Objectives

5. Analyze your response to Point 4. Respond to the following question (bullet form): For me to develop the competencies listed in Point 4 what do I need to learn? For each Competency identify the associated Learning Objectives. **Note: A Learning Objective must contain the word "learn" in it and include transformative words from Bloom's Taxonomy** (see lecture 1).
 - a. **Assess** whether each of the learning objectives contains the word **Learn** and **transformation words** for the appropriate domain of knowledge. If not **improve**.
 - b. **Assess** whether the set of 5 proposed learning objectives span a few domains of learning. If not **improve**.
6. Classify, refine the list. Prioritize, modify / refine and list your 5 Learning Objectives for this class. Justify.

Relate Competencies and Learning Objectives

7. Illustrate the relationship between the competencies identified in Step 4 and Step 6. Comment on the efficacy of the relationship.
 - a. **Assess** whether the Competencies and Learning Objectives are suitably labeled. If not **improve**.
 - b. **Assess** whether the transformative words in the Learning Objectives are highlighted in the illustration.
 - c. **Verify** whether what you have illustrated is in harmony with what you have written under Point 1 in this evaluation exercise. If not **improve**.

Value

8. Analyze what you have written in Points 4 and 6 and answer the following questions: What is it you really wish to achieve as a result of taking this course? What have you learned as a result of doing this assignment? Hint: Summarize using transformative words from Bloom's Taxonomy and associated competencies.

Continuous Improvement

In tabular form, record the date and your feelings as you read this at various times during the course. Please modify as you proceed through the semester. Note: You will be making an entry every week. Start off right. ☺

Fig. 7. Assignment 0

In Assignment 7 the students were required to put together all the well-scaffolded pieces they had worked on during the semester. That is, they collaboratively had to write a complete book in which each chapter was dedicated to one of the assignments. The difficult task here was to tie everything together to create a coherent train of thought, starting from the background information on Friedman's flat world, Procter and Gamble's Connect and Develop approach for Open Innovation, Bloom's Taxonomy of Learning, the Q4S, the topics of the subsequent assignments as well as the industrial mini-consulting projects that were embedded into the assignments. In addition, the students had to answer the Question for the Semester.

4.2.4 Learning essays

Learning essays are weekly submissions in which the students usually review and explore topics from the lectures in the context of their personal semester goals (learning objectives and meta-competencies). To guide the students, at the end of each lecture specific guiding questions are suggested that may help them to better relate the lecture content to the big picture of the course. The students also have the freedom to choose other course-related themes for their learning essays. A core aspect of the learning essays is that the students learn how to create new knowledge and enhance their critical thinking skills. Furthermore students learn how to evaluate their work and their progress towards their personal goals from Assignment 0. The structure of learning essays is scaffolded to address learning objectives and competencies (as shown below).

At the end of the semester the students reflect on their learning in the Semester Learning Essay by relating it to a non-engineering analogy or metaphor (e.g., football, cooking, golfing and writing poems). Here, the students can show that they really progressed in achieving their personal semester goals.

Structure of a Learning Essay

Tag Line – Core Notion

Your A0 Goals – Competencies and Learning Objectives

Preamble: Provide context for your learning essay

Observe: State the facts (as per author, professor)

Reflect: Look at the observations from different perspectives. Pose questions and answer them

Articulate: New insights and knowledge

Key phrases: I learned x, I realized x, etc.

Value = Utility / Time Invested

With respect to A0 goals, answer to Q4S, project, etc.

4.2.5 Individual and group feedback

In ME6102 no grades are given until the end of the semester. Hence, the students can concentrate only on their progress towards achieving their personal learning objectives

articulated in A0 for the semester. To ensure that the students are on the right track, the orchestrators facilitate self-assessment and provide feedback to the individual and the group through formative assessment of all submissions (assignments and learning essays) throughout the semester. Through Assignment 0, the orchestrators get to know the students and thus are able to provide individual feedback on all submissions according to the students' individual semester goals. To remind both the student and the orchestrator of these goals the students state them at the beginning of all learning essays and assignments and evaluate their learning with regard to these goals. This means that the students get constructive feedback which helps them make progress towards their individual semester goals. Students are expected to record the comments they get on their work in a journal and demonstrate that they utilize them in the following submissions. In doing so, the students can better realize their progress, which can increase their motivation.

4.2.6 Best practices

Learning essays and assignments, that have the potential to add value to the learning of others become "best practices" and are shared with the entire class. Often "best practices" from former students of the course are also discussed in class or presented on the course website. This aspect of the presented approach enables collective learning; students learn from and about each other, get inspired and can build on others work to develop new knowledge. A positive side effect is also an additional incentive to become author of a "best practice" and the experience that an individual's work is taken seriously by others.

4.2.7 Project

The project is another avenue for collaborative learning experience. In the project, the students are expected to validate a part of their answer to the Q4S. Validation is an important aspect of the course because it helps students to learn how to critically evaluate their proposed answer to the Q4S. This relates to the highest level in the Bloom's taxonomy. The students are free to choose the topic of the project related to their research or other personal interests. Examples from the past are "human centered design of a bicycle through a simplified CAD interface for customer interaction" and "motivation and incentive models in online communities and mass collaborative projects". The typical group size is two to four members. This cooperative learning experience is integrated into the presented approach to increase the depth of learning through group learning and discussions.

4.2.8 AO-EOS and self-grading

At the end of the semester, students are called on to close the loop with regard to what each has learned – to what extent each has achieved the competencies and the associated learning objectives proposed in A0 and refined through the semester. The students are required to revisit all their submissions, reflect on the feedback that was provided and take stock of how much each of the learning activities throughout the semester have actually helped them to attain the desired competencies and meet the corresponding learning objectives. To what degree have they learnt how to learn? This process of reflective practice is presented to the students by means of A0-EOS, an extended end-of-semester version of the original Assignment 0.

Assignment 0 – End of Semester

...

A0 Completion - Individual

10. Revisit Value = Utility / Time Invested
Summarize ...
Assignment 1: Summarize Part 6
Assignment 2: Summarize Part 4
Assignment 3 through 6: Summarize Part 3
11. In tabular form, in the context of a learning organization, outline the strategy that you followed in defining your "mental model" for Assignments 3 through 6 AND your contributions to the collaborative assignment.
12. In tabular form summarize your contributions to Assignments 3 through 7 under the following headings:
 - a. Themes / ideas proposed by you and adopted by the team ...
 - b. Themes / ideas proposed by others that were adopted by the team ...
 - c. Rate the contribution of others¹: A – above average. B – average. C – below average. You are encouraged to use + and – for the grades you assign. Justify.
 - d. In the context of 12 c rate your own contribution: A – above average. B – average. C – below average. Justify.
13. In tabular form, please convey how you progressed in attaining your competencies and learning objectives throughout the semester.
14. In graphical format, please convey the degree to which you attained the identified competencies and learning objectives.
15. Analyze what you have written in Steps 10 through 14. Then, critically evaluate your performance (in terms of competencies and learning objectives) throughout the semester; be sure to use action words from Bloom's taxonomy. Comment on the level of attainment in Step 14, what you would do differently if you had to do it over, and plans for the future.

Grade for A0 End of Semester

16. Reflect on your performance in this class throughout the semester. In tabular form, please suggest a grade for yourself in the following categories and justify²:
 - a. Contribution to the collective Question for the Semester. Justify.
 - b. Degree to which you attained your competencies and learning objectives and why.
 - c. Degree to which you learned what you would do differently and why.
17. Overall grade you award yourself for this submission. Not all items are equally important to determine your grade for the course. You may weight items 16a through 16c as shown below.
 - 16a - 30 to 50%
 - 16b - 30 to 50%
 - 16c - 10 to 20%

¹ A+ (4.3). A (4.0). A-(3.7). B+(3.3). B (3.0). B-(2.7). C+(2.3). C (2.0). C-(1.7). D (1.0). F (0.0)

² Be sure to reference elements of your responses to Items 10 through 15.

Fig. 8. Fragment of Assignment 0 – End of Semester (A0-EOS)

In addition to revisiting the questions of A0, the students are called on to reflect on their learning process, the quality of their contributions to the various assignments, the value gained with respect to attaining their individual learning objectives and competencies as well as the value added to the overall ME6102 Learning Organization. Finally, based upon this self-reflection, the students are asked to propose a grading scheme for evaluating their own work as well as that of their peers. This includes developing a comprehensive assessment rubric showing the categories of work to be assessed along with justifications for

the various degrees of achievement, as well as the articulation of the specific grades they believe they have earned.

In summary, the underlying architecture of the course facilitates mass-customization. While the course does require significant commitment from the orchestrators, its architecture with a core element and customizable components makes it manageable.

5. Closing comments

"Any customer can have a car painted any color that he wants so long as it is black" [39]

This well-known quote attributed to Henry Ford epitomizes the traditional concept of mass production. While this paradigm was successful in most part the 20th century, most companies today realize that their long-term success cannot be guaranteed by focusing on a single product. Instead, companies must generate a continuous stream of value-rich products. Unfortunately, the framework of engineering education is still built on the traditional mass production paradigm. Educational institutions around the world are focused on mass-producing graduates with similar skills and knowledge. Many degree programs have changed very little from what they were various decades ago. Educational institutions are generally slower in adapting to the changing workplace. In this chapter, we emphasize that the success of education programs is dependent on the ability to personalize educational experiences. We argue that the need for mass-customization is as much important in education as it is in product development.

Along with the advent of globalization came a huge variety of new job profiles that do not correspond well to what is offered through traditional education and training programs. It is clear that the work force of near tomorrow will have to be very agile and versatile in terms of the competencies and skills to be obtained and that learning how to learn, i.e., becoming a self-motivated, self-organized learner. In light of this, the National Academy of Engineering (NAE) identified Advanced Personalized Learning as one of the Grand Challenges of our time [40]. In response to this, many educational institutions around the world have started developing on-demand digital curricula to drive independent, self-directed learning. One way of facilitating this is to utilize the characteristics of mass-customization, as presented in this chapter, and apply them to curriculum and program design on a larger scale. In terms of a long-term vision, it may be conceivable to offer personalized educational programs based on resources drawn from anywhere in the world. We are aware that current business models do not necessarily support such ideas. However, we believe in the famous Walt Disney quote: "If you can dream it you can do it".

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